

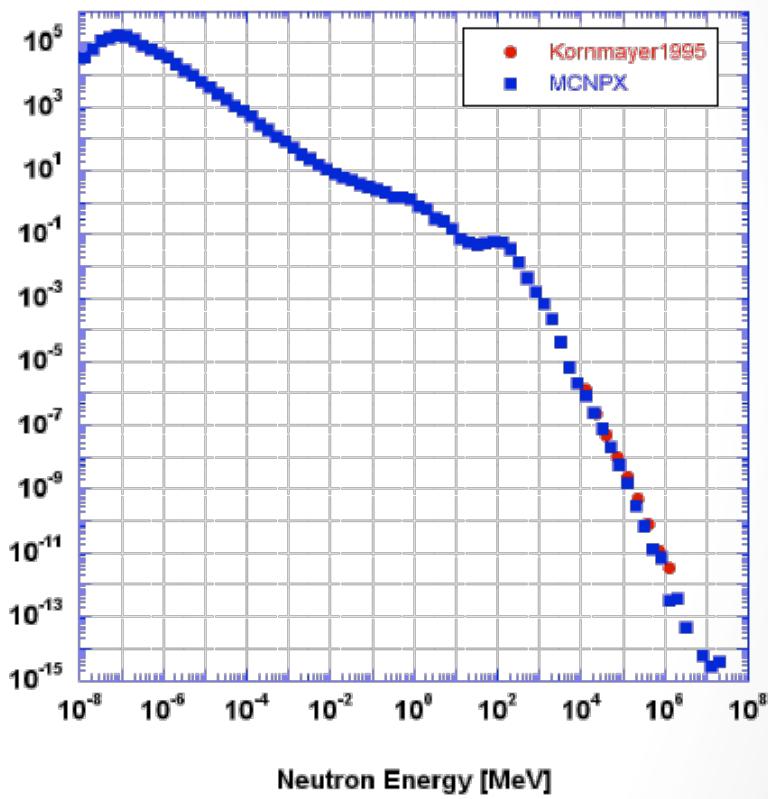
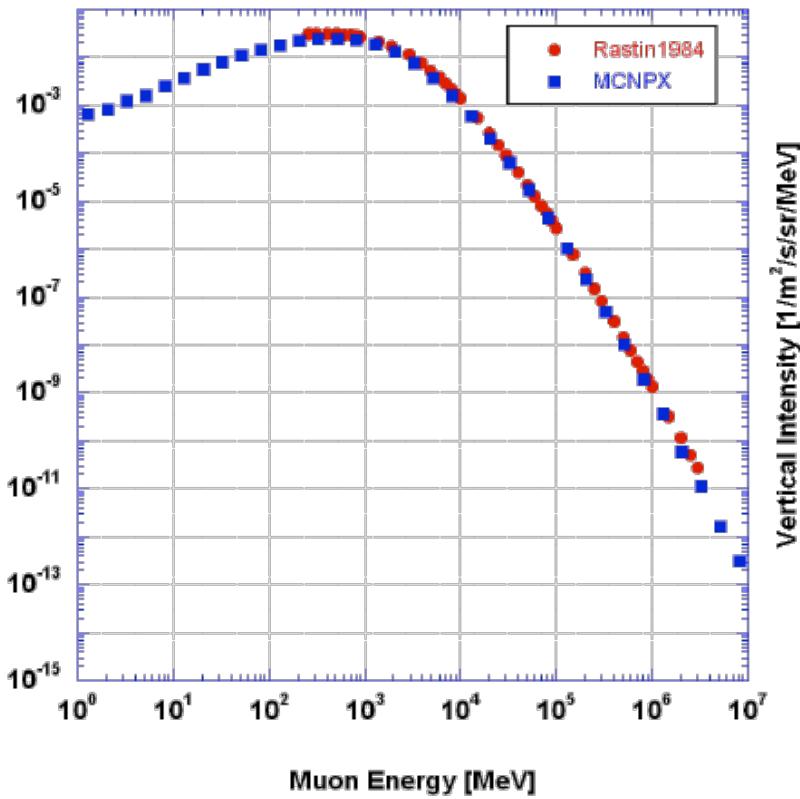
Cosmic Ray Neutrons in Liquid Argon Detectors on the Surface

Geoffrey Mills

Introduction

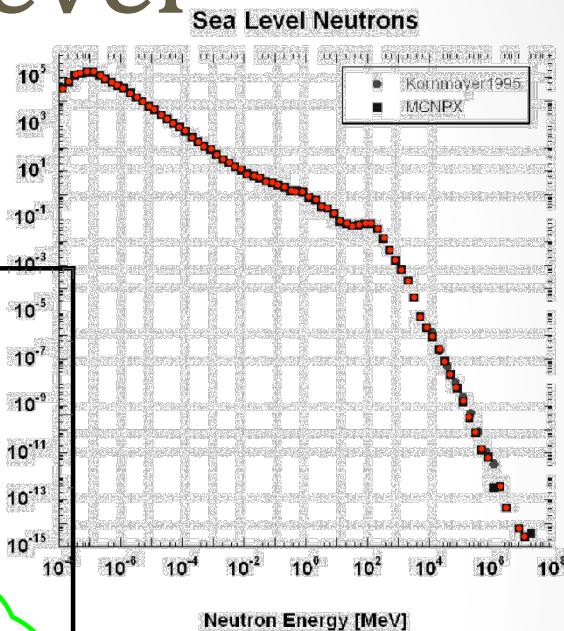
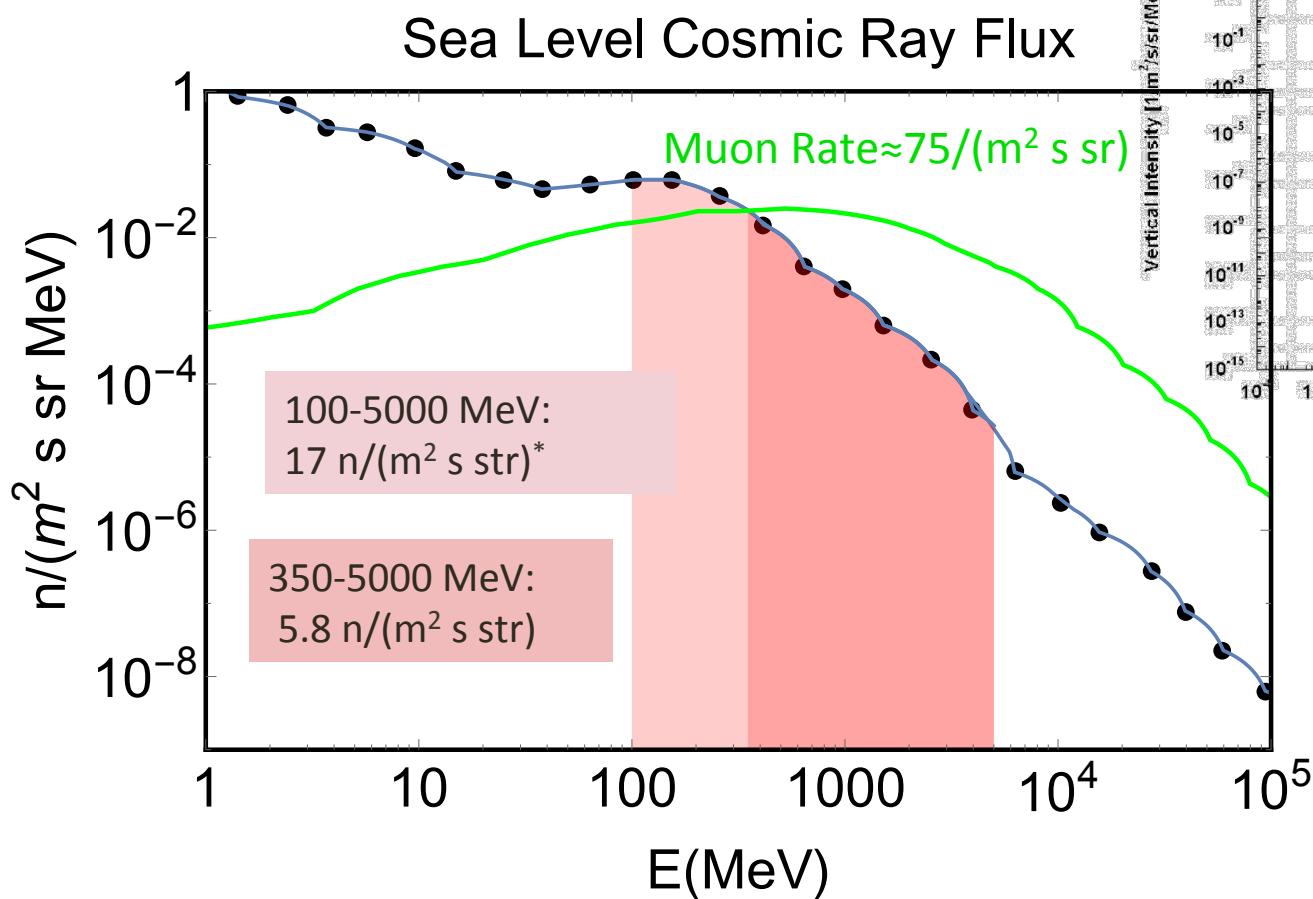
- Cosmic ray rates in a liquid argon TPC detector on the surface of the earth are much larger than previously operated LAr TPCs that were underground
- Types of cosmic rays:
 - Muons (traverse entire detector)
 - Photons: absorbed in the first few radiation lengths ($X_0 \sim 14\text{cm}$)
 - Protons: entrance track in TPC and interact ($\lambda_{\text{int}} \sim 86\text{cm}$)
 - Neutrons: no entrance track, only see interaction ($\lambda_{\text{int}} \sim 86\text{cm}$)
- Muons and protons can be rejected because of the entering track, and photons can be rejected via proximity of shower to the edge of the TPC ($X_0 \approx 14\text{cm}$)
- Neutrons will look very similar to NC neutrino events, e.g. elastic scattering, pion production ($E_n > 550\text{ MeV}$)

Muon and Neutron Fluxes²



² CRY Simulation Physics Document

Neutron Flux at Sea Level



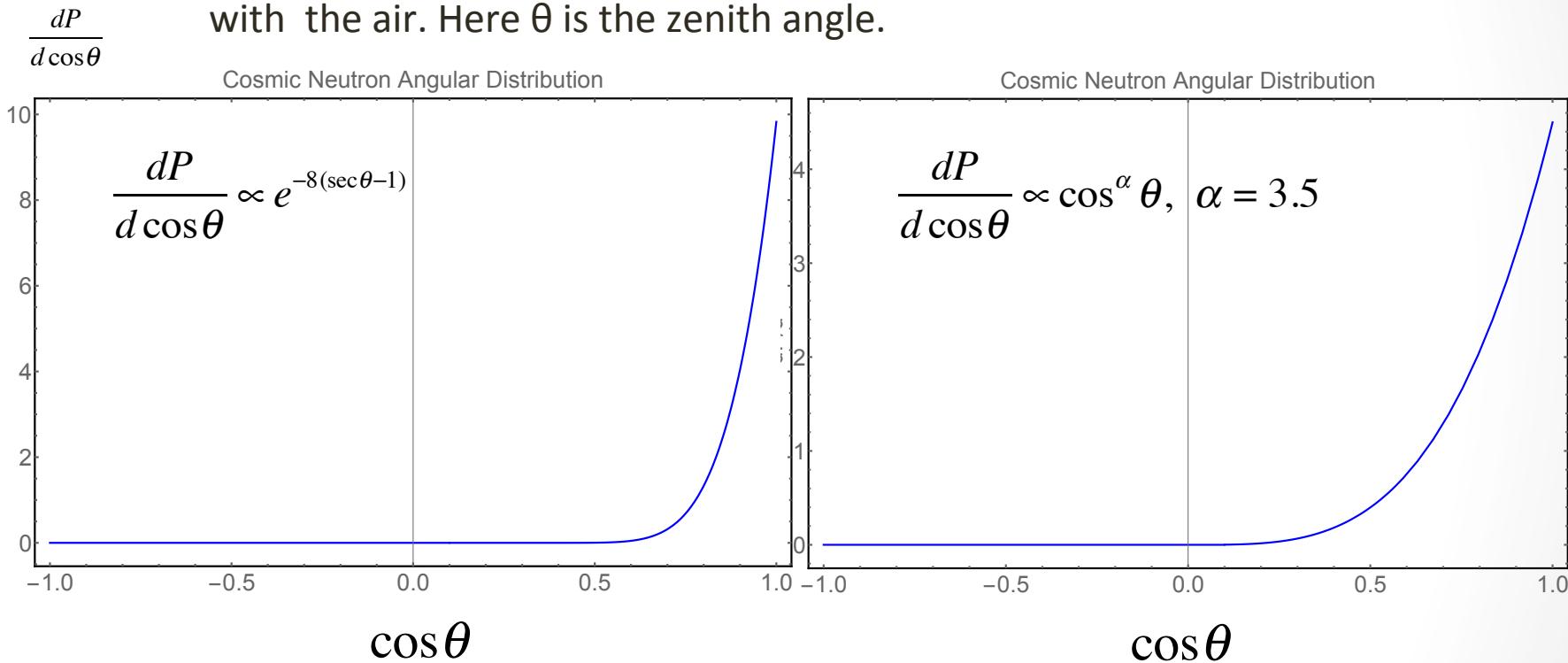
* NB the muon rate is roughly $70 \mu/(\text{m}^2 \text{ s str})$ which is about $1/(\text{cm}^2 \text{ min})$

Assumptions (discussed later):

- Protons on target: 1.3×10^{21}
- Number of 1.6 μ s booster batches: 2.9×10^8
- Live time: 464 seconds
- μ BooNE effective area: 20.2 m²
- Neutron zenith angle distribution $\approx \cos^\alpha \theta_{\text{zen}}$ ($\alpha \approx 3.5 \pm 1.2$)
- Overburden interaction length ≈ 0.4 m

Neutron Angular Distribution

Angular dependence for cosmic neutrons is much stronger than for muons because of nuclear interactions with the air. Here θ is the zenith angle.



Reasonable variations produce overall rate changes of $\sim 30\%$ in detector acceptance

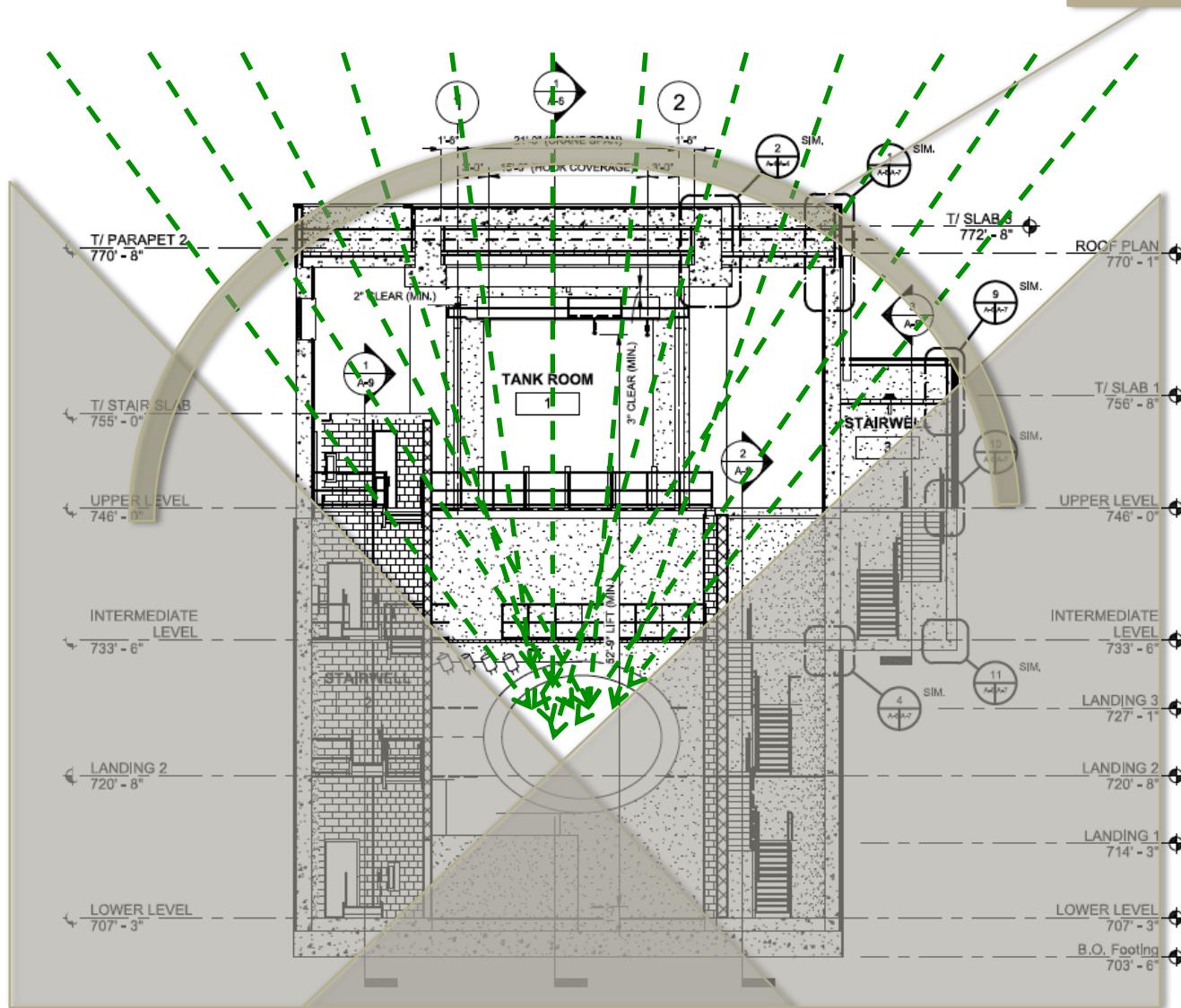
Effect of Zenith Distribution

Angular Shape	Neutrons above 350 MeV (6 E 20 POT)	Neutrons above 100 MeV (6 E 20 POT)
$\mu^{3.5}$	20k	60k
$\mu^{4.5}$	23k	64k
$\mu^{5.5}$	23k	68k
$\mu^{2.5}$	18k	54k
$\text{Exp}[-8(1/\mu - 1)]$	25k	73k
$\text{Exp}[-12(1/\mu - 1)]$	26k	75k
$\text{Exp}[-6(1/\mu - 1)]$	25k	72k

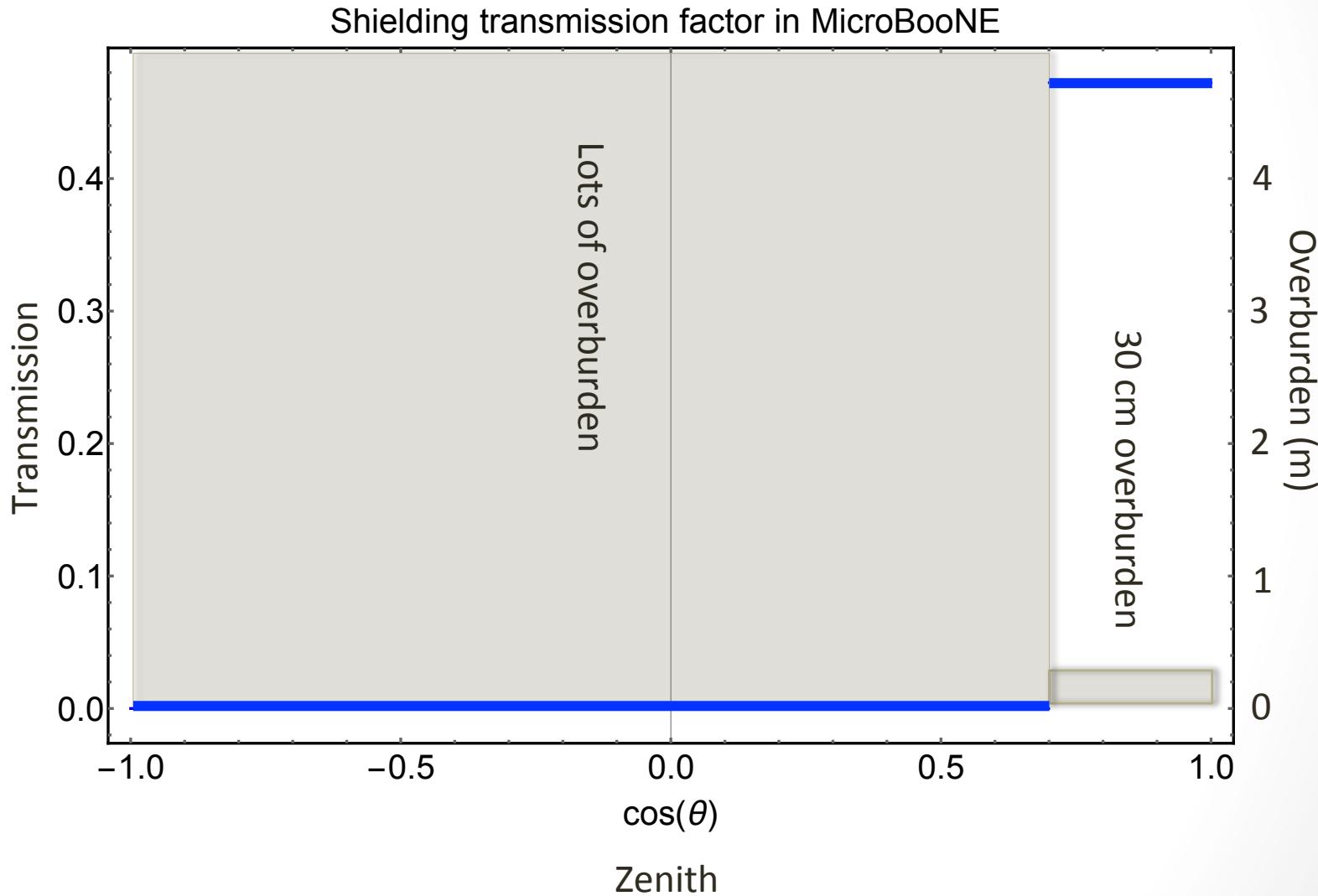
- Reasonable variations give $\approx 20\%$ range of values

Neutron Transmission

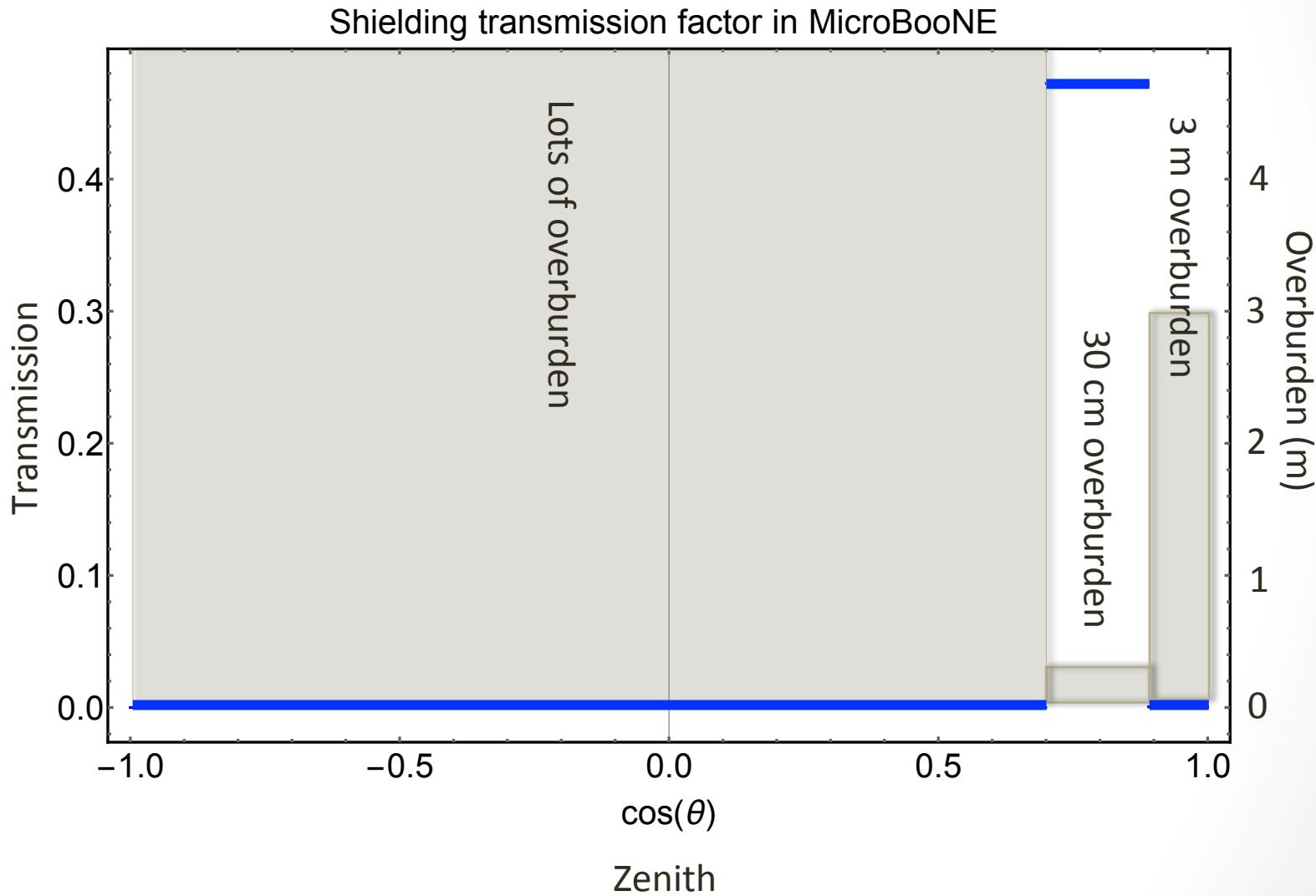
Overburden



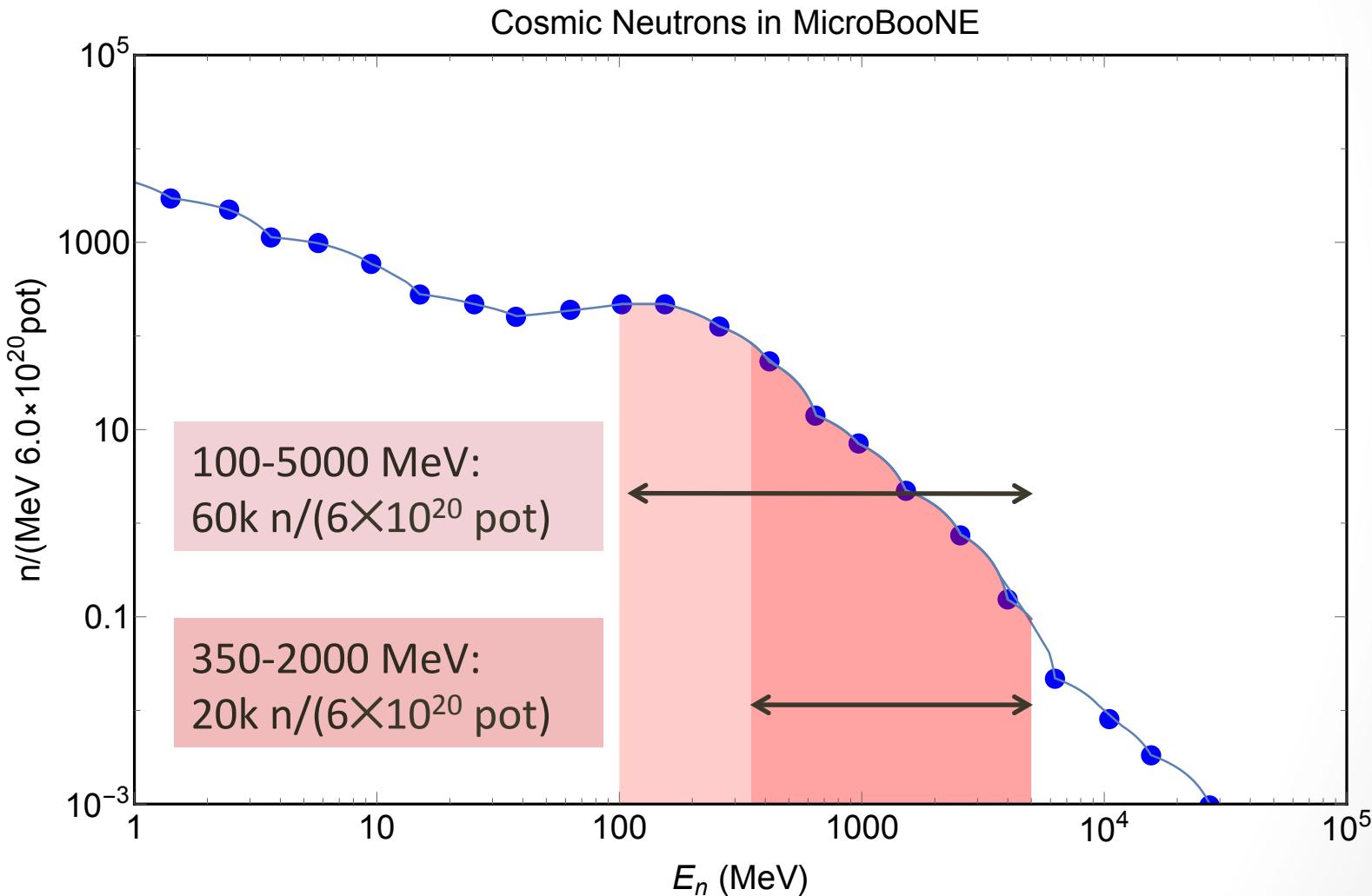
Shielding Without Overburden



Shielding With Rooftop Overburden



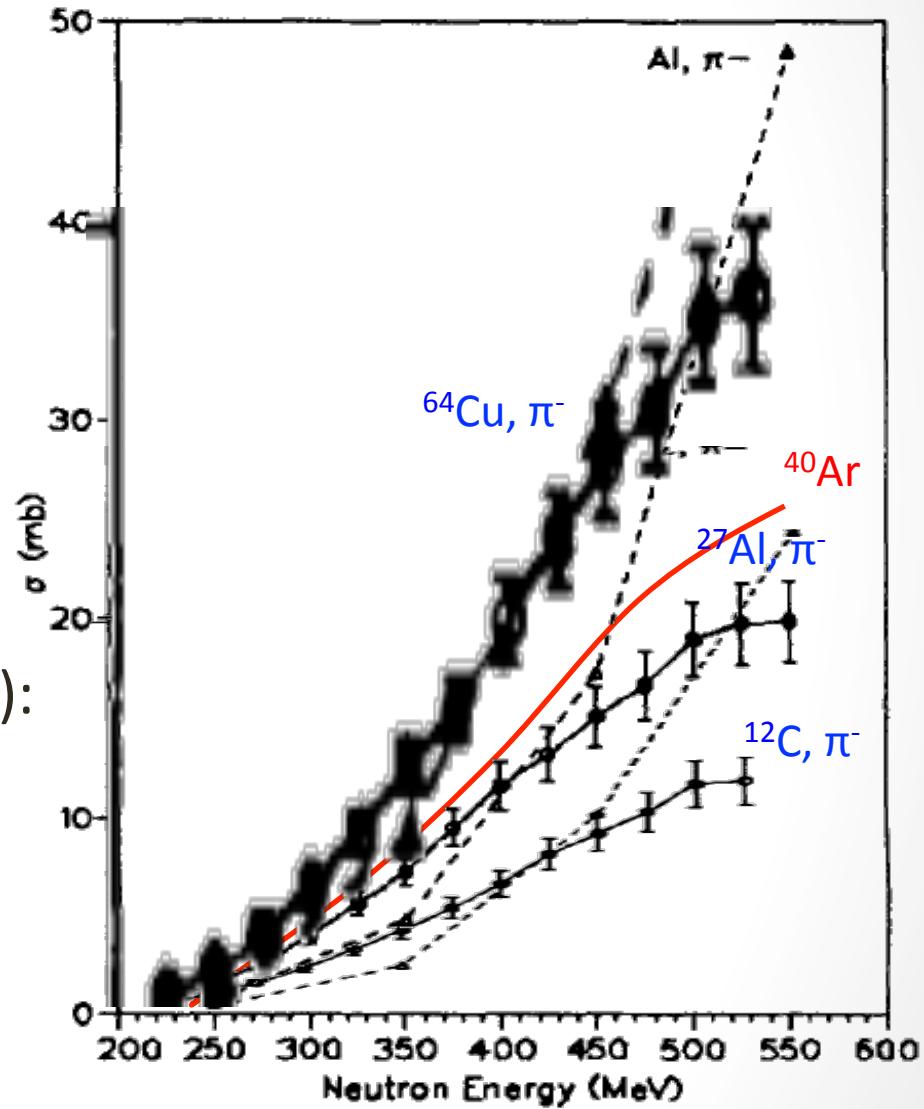
Neutron Rates in uBooNE



π^0, γ Production in $n\text{-Ar}$ Reactions

(Crude estimate using CG coeff)

- neutron-Ar:
 - $\sigma_{\text{tot}} \approx 300 \text{ mb}$
 - $\sigma_{\Delta} \approx 125 \text{ mb}$
 - $\sigma_{\pi^0} \approx 4\sigma_{\pi^-} \approx 100 \text{ mb}$
- $\approx 1/3$ produce a π^0
- $\approx 0.3 \%$ radiative Δ decay
- Result (inside $1.6\mu\text{s}$ window):
 - $\approx 7\text{k } \pi^0$ events
 - ≈ 60 radiative Δ decay



Summary

- Significant number of cosmic ray neutrons are expected to sneak into the detector during the $1.6 \mu\text{s}$ beam window
 - 100-350 MeV : $\sim 60k \text{ n}/13 \times 10^{20} \text{ pot}$ (mostly elastic scattering)
 - 350-2000 MeV : $\sim 20k \text{ n}/13 \times 10^{20} \text{ pot}$ (some π^- and π^0 production)
- Crude estimate of potential background sources:
 - $20k \pi^0$
 - 180 radiative Δ decays

Effective Area

- Geometric acceptance for neutrons intersecting the top surface of detector
- μB Effective area: 20.2 m^2 ($A=26.5 \text{ m}^2$)

